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955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 12082

SUBJECT: Parameter Sensitivities of Preliminary Apollo 15 Trajectories - Case 310

DATE: December 31, 1970

FROM: J. A. Sorensen

ABSTRACT

The LM descent trajectory being considered for Apollo 15 has a 25° elevation angle at high gate. The increase from 16° allows the crew to get a much closer first look at the landing area. The ΔV cost and visibility time sensitivities of 25° trajectories to variations of high gate altitude, vertical descent rate at 500 ft altitude, and low gate altitude are determined. It is recommended that lowering the automatic low gate altitude from the proposed 200 ft to 100 ft be considered further.

(NASA-CR-116272) PARAMETER SENSITIVITIES OF PRELIMINARY APOLLO 15 TRAJECTORIES (Bellcomm, Inc.) 15 p

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MEMORANDUM FOR FILE

I. INTRODUCTION

The LM descent trajectory being considered for Apollo 15 has a larger high gate elevation angle* above the landing site than do trajectories for the previous flights. This angle has been raised from 16° to 25° for about the same altitude (∿7500 ft), and therefore reduces the high gate point's range from the landing site. The result is that the LM crew gets a much closer first look at the landing area following pitchover at the beginning of the visibility phase. The solid angle described by a crater at the site is about 3.5 times larger from this closer range.

The crew's ability to recognize the landing area features has also been improved by designing the trajectory with a nearly constant look angle** during most of the visibility phase. This constant look angle enables the LM Commander to determine more accurately the position of the desired landing site relative to the site to which the LM is being automatically steered. (The direction to this automatic site is displayed by the guidance computer so the Commander can determine its location in the LM window.) An error between the designated and desired landing sites is subsequently removed by Commander redesignation of the automatic site.

A previous memo (Ref. 1) considered the possible use of steep descent trajectories to solve the visibility washout problem associated with the high sun elevation angles for T + 24 hr launches. The major effort was to minimize ΔV while maintaining a high elevation angle with no attempt to keep the look angle constant.

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*The elevation angle is the angle between the line-of-sight from the LM to the landing site and the horizontal plane through the site.

**The look angle is the angle between the forward body axis of the LM and the line-of-sight to the designated landing point.

This memo investigates the characteristic velocity (ΔV) cost and look time sensitivities to variations of certain parameters affecting a trajectory with a high gate elevation angle of 25°. The parameters studied are the high gate altitude, the vertical descent rate at 500 ft, and the low gate altitude (altitude of automatic guidance target switch, currently 200 ft). Each of the trajectories studied is designed with a nearly constant look angle during the visibility phase.

First, the trajectory design is discussed. Then the parameter sensitivities are presented.

II. CONSTANT LOOK ANGLE TRAJECTORY DESIGN

Trajectory design consists of selecting the explicit guidance steering coefficients (targets) and the trajectory's initial state so that the resulting trajectory has the required characteristics. In the design procedure followed for this memo, the visibility phase is first shaped to produce a nearly constant look angle. Then, the braking phase is designed so that the desired high gate state is reached with minimum ΔV.

The steps followed in designing the visibility phase are:

1. The high gate altitude and elevation angle above the landing site are first chosen. In this study, the "nominal" trajectory had a high gate elevation angle of 25°. This fixes the high gate range.

2. The low gate position and velocity are chosen. The nominal altitude and vertical rate were 200 ft and 5 ft/sec. The horizontal position and velocity were picked to produce acceptable touchdown conditions.

3. The vertical rate at 500 ft is chosen. For the nominal trajectory, this was 16 ft/sec.

4. The magnitude of thrust at high gate is chosen. In this study, it was 57% of full thrust.

5. The minimum elevation angle of the visibility phase is chosen. This angle is used to control the look angle time history during the approach.

Figure 1 shows three look angle profiles for trajectories with different minimum elevation angles. Decreasing the minimum elevation angle raises the initial look angle to the designated landing site.

6. The target coefficients are determined iteratively so that the visibility phase requires minimum ΔV, and the constraints of (3)-(5) are met.

The braking phase ignition state and targets are selected so that (a) the initial state of the visibility phase (high gate) previously chosen is met, (b) the trajectory has 120 sec of throttle-down time, (c) thrust during the throttle-down portion does not exceed 58% of full thrust, and (d) the ΔV of this phase is minimized.

III. PARAMETER SENSITIVITY

The trajectories discussed in this section were designed with the Apollo 14 weight and thrust models, but the sensitivities should be typical for the Apollo 15 vehicle.

The effect of varying high gate altitude on ΔV and look time is shown in Fig. 2. Look time is defined here as the amount of time the look angle is above the 55° line in the window. Raising the high gate altitude raises the ΔV cost to automatically land by about 30 ft/sec per 1000 ft. The tradeoff here is that the look time is increased by about 7 sec per 1000 ft increase in high gate altitude.

Raising the high gate altitude has no effect on downrange or crossrange LPD costs if the redesignations are made from the same altitude. However, raising high gate may allow the initial redesignations to be made at a higher altitude which would reduce the fuel cost.

Figure 3 illustrates the effect of changing the vertical descent speed constraint at the 500 ft altitude point on the trajectory. These results are for a trajectory with a 7000 ft high gate and a 200 ft low gate. Increasing the vertical rate one ft/sec decreases the ΔV 18 ft/sec. Also, a one ft/sec increase raises the minimum elevation angle about 0.5°. An increased minimum elevation angle can be an advantage for avoiding visibility washout.

By increasing the vertical rate at 500 ft altitude from 15 ft/sec to 19 ft/sec, the look time was decreased less than 5 sec. Also, changing this rate had a negligible effect on LPD costs for downrange and crossrange redesignations.

To determine the effect of changing the automatic low gate altitude, another trajectory was designed with a 100 ft low gate altitude. The vertical rate at low gate was kept at 5 ft/sec. A parametric comparison of these trajectories follows:

	100 ft Low Gate	200 ft Low Gate
ΔV to automatically land - fps	6592.	6628.
Look time above 55° - sec	114.	94.
Range where site drops below 55° - ft	200.	550.
Minimum elevation angle - deg	17.5	20.6

The 36 ft/sec ΔV that the 100 ft low gate trajectory saves represents about 7 seconds of additional hover time capability or 120 lb of additional payload. For normal sun elevation angles, the crew visibility time also seems to be enhanced by lowering the target low gate. Figure 4 compares the look angle time history of these two trajectories. The 100 ft low gate trajectory look angle is higher in the window, but it is also less constant.

Figure 5 compares the vertical descent rate of the two trajectories below 600 ft altitude. The ΔV savings of the 100 ft low gate trajectory can be explained by the generally higher vertical rate below 400 ft. This causes less time to elapse until touchdown.

The states of the two trajectories at 500 ft altitude are:

	100 ft Low Gate	200 ft Low Gate
Range	-1320.	- 860.
Vertical Speed - ft/sec	- 16.	- 16.
Horizontal Speed - ft/sec	63.	51.
Look Angle - deg	38.	49.
Time From High Gate - sec	88.	86.
ΔV Used - ft/sec	6280.	6260.

The horizontal components of position and velocity are larger for the 100 ft low gate trajectory, and this is generally true for the last portion of the trajectory. This occurs because the trajectory is designed with a smaller minimum elevation angle. The resulting trajectory profiles are illustrated in Fig. 6. The trajectory with the 100 ft low gate more nearly resembles the Apollo 14 trajectory below 500 ft; it should therefore have smaller ΔV costs for downrange-crossrange site redesignations during manual control.

IV. CONCLUSIONS

The LM descent trajectories being considered for the Apollo 15 flight have the following sensitivities:

1. Raising the high gate altitude 1000 ft increases the ΔV cost to automatically land 30 ft/sec and increases the visibility phase look time about 7 seconds.

2. Increasing the vertical descent speed at 500 ft altitude one ft/sec decreases the ΔV to automatically land 18 ft/sec and raises the trajectory's minimum elevation angle about 0.5°.

3. Lowering the automatic low gate altitude from 200 to 100 ft provides the following advantages:

   a) The ΔV to automatic landing is reduced (36 ft/sec in the example).

   b) The look time available to the crew is increased (20 sec in the example).

   c) The range where the automatic landing site drops below 55° in the LM window is reduced (from 550 ft to 200 ft in the example).

   d) The last part of the trajectory is flatter and with faster horizontal speeds. This should lower the landing site redesignation costs during the manual portion of the descent control.

Points 1 and 2 give the trajectory designer sensitivities which can be used for trading off ΔV cost and look time.

It is recommended that lowering the automatic low gate altitude from 200 ft to 100 ft for the 25° trajectories be strongly considered.

John A. Sorensen

2014-JAS-ksc

J. A. Sorensen

Attachments
Figures 1-6

REFERENCE

G. M. Cauwels and J. A. Sorensen, "Preliminary Study of Steep LM Descent Trajectories Suitable for a One-Day Launch Delay," Case 310, Bellcomm Memorandum for File, December 21, 1970.

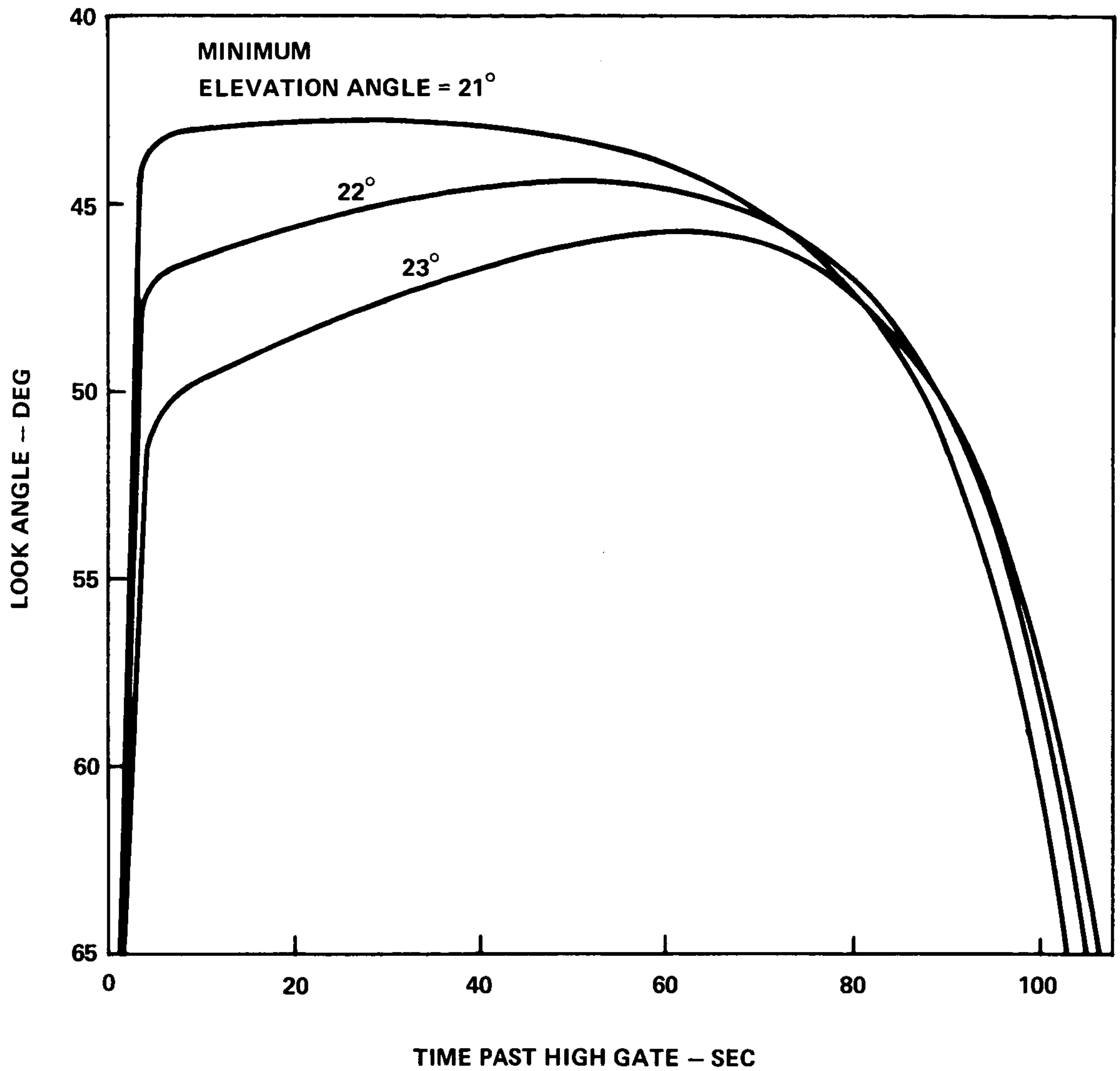

FIGURE 1 - EFFECT ON THE VISIBILITY PHASE'S LOOK ANGLE TIME HISTORY CAUSED BY CHANGING THE MINIMUM ELEVATION ANGLE

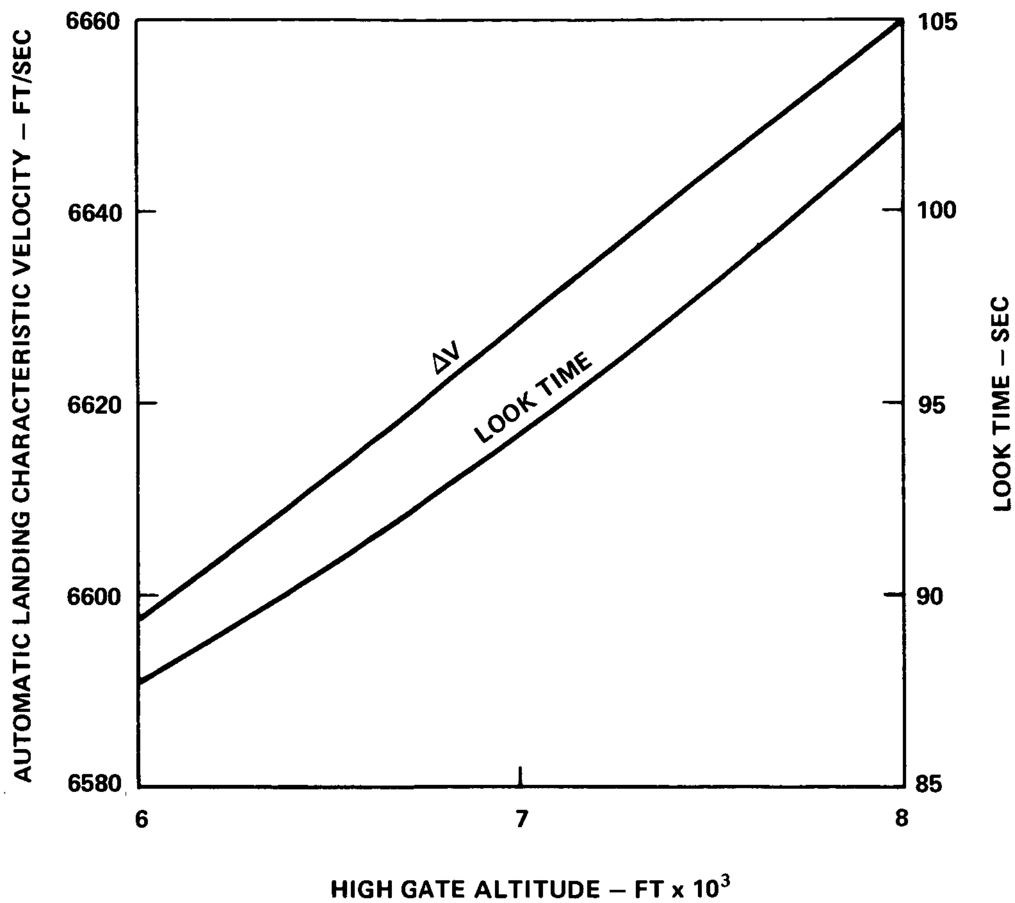

FIGURE 2 - VARIATION OF ΔV AND LOOK TIME AS A FUNCTION OF TARGETED HIGH GATE ALTITUDE

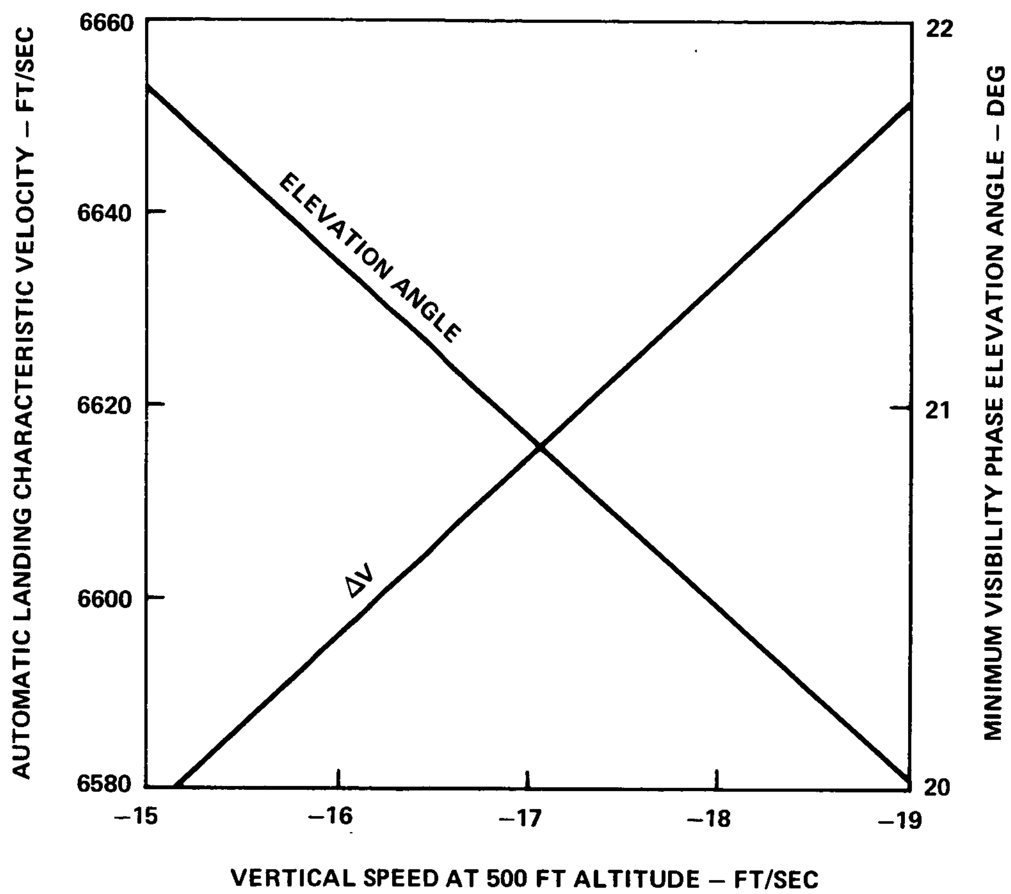

FIGURE 3 - VARIATION OF ΔV AS A FUNCTION OF VERTICAL SPEED AT 500 FT. ALSO SHOWN IS MINIMUM ELEVATION ANGLE REQUIRED TO ACHIEVE NEARLY CONSTANT LOOK ANGLES

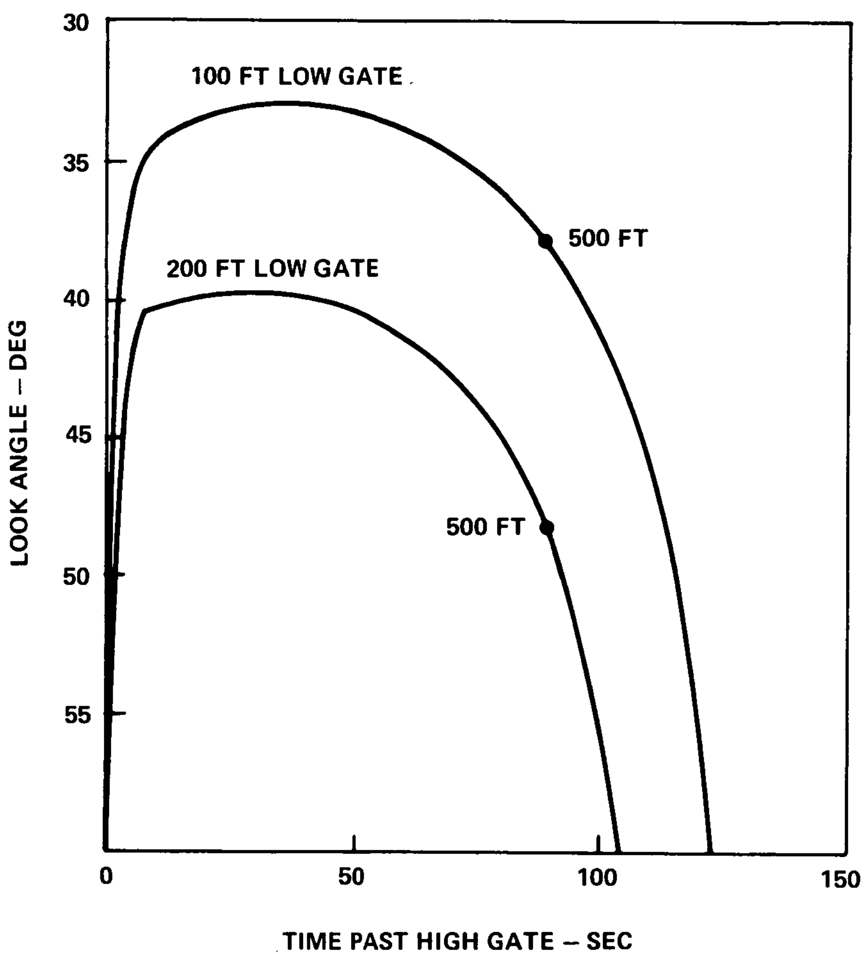

FIGURE 4 - COMPARISON OF LOOK ANGLES FOR TRAJECTORIES WITH 100 FT AND 200 FT LOW GATES. 500 FT ALTITUDE POINTS ARE INDICATED

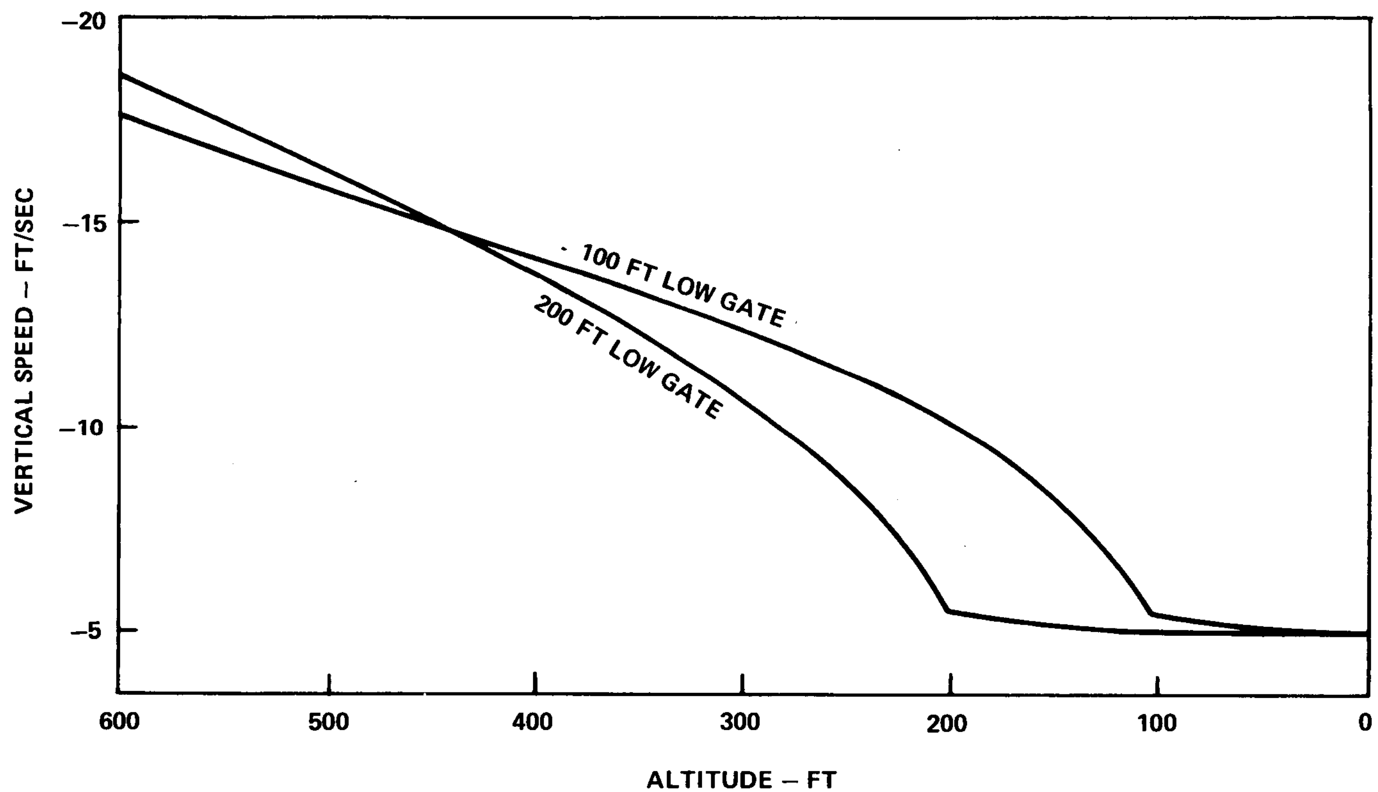

FIGURE 5 - COMPARISON OF VERTICAL RATES FOR TRAJECTORIES WITH 100 FT AND 200 FT LOW GATES

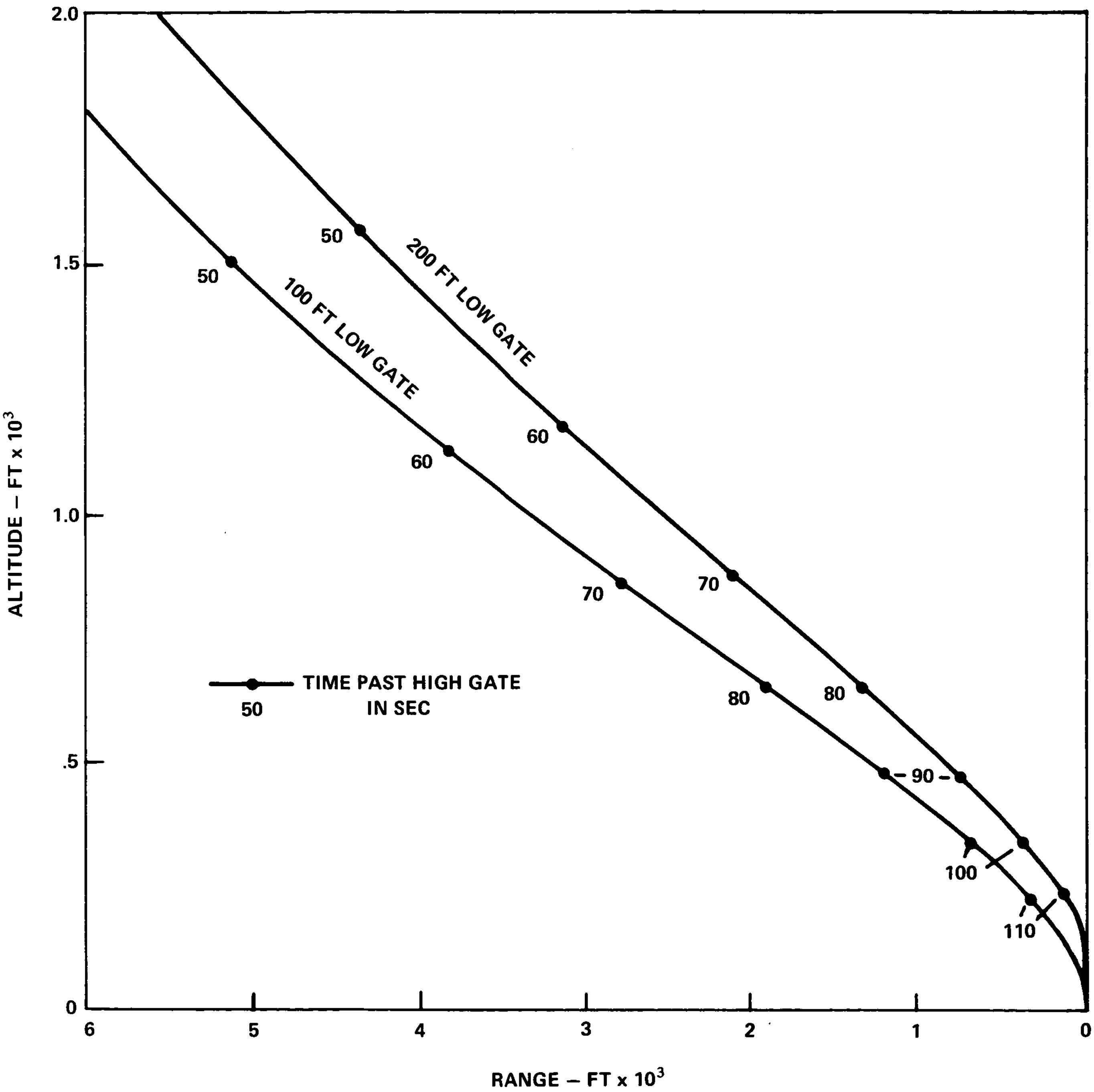

FIGURE 6 - COMPARISON OF TRAJECTORY PROFILES WITH 100 FT AND 200 FT LOW GATES

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From: J. A. Sorensen

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